Fabrication additive
&
besoins en CND

Institut de Recherche en Génie Civil et Mécanique,
Equipe Etat Mécanique et Microstructure des Matériaux (E3M)

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La fabrication additive : principe - intérêt

Présentation de différents procédés

Réaliser un cordon

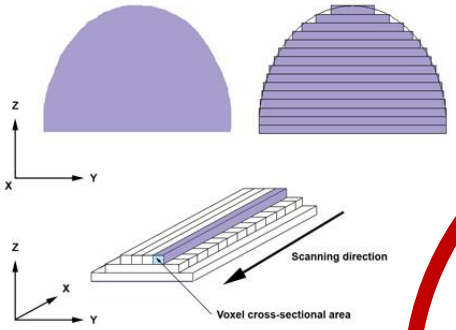
Réaliser un mur

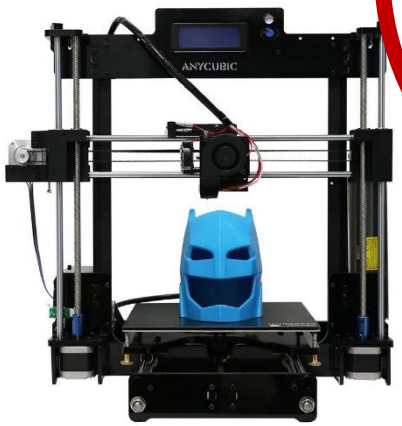
Réaliser une structure pleine

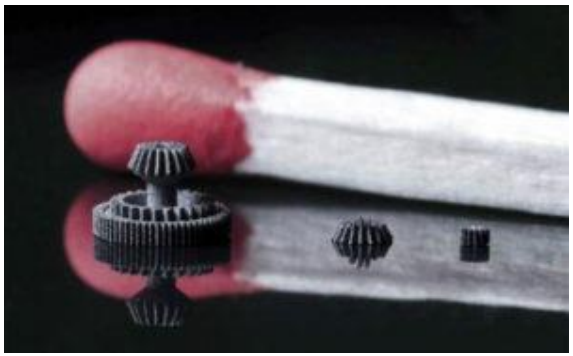
Réaliser une pièce

Conclusion

Principe


Z
Y
X
Z
X
Y
Scanning direction
Voxel cross-sectional area


ANYCUBIC



Avantages

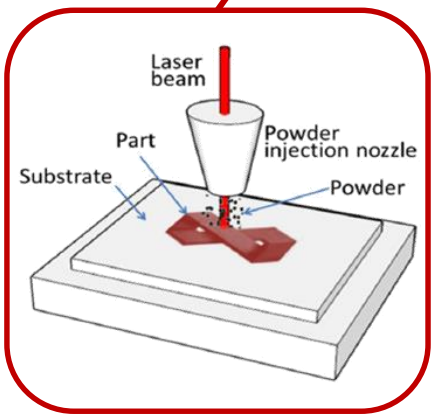
Plus rapide	Plus souple	Plus écologique	Plus économique
Pas d'outil Pas de moule	Géométrie complexe Multi-matériaux Plus esthétique Personnalisation	Pas d'enlèvement de matière Moins de matière Moins de transport	Pour toutes ces raisons

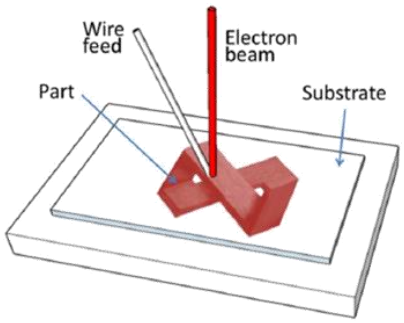
Inconvénients :

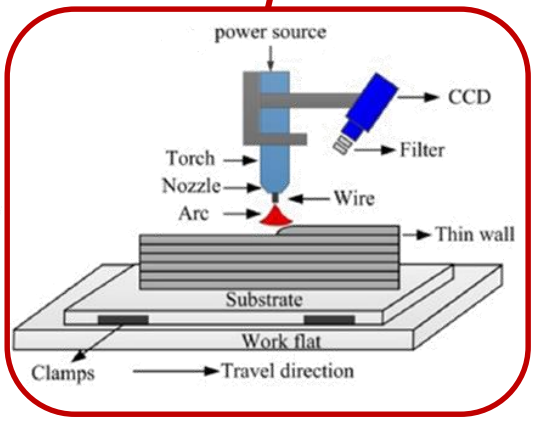
- Nécessité d'un post-traitement
- Nuances limitées de matériaux
- Limitation aux petites séries

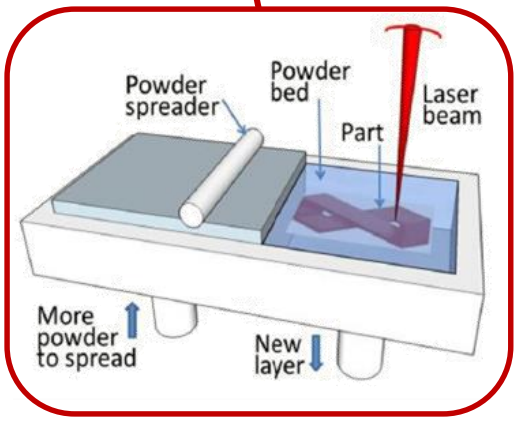
Les procédés de fabrication additive avec fusion (matériaux métalliques)

Procédé	Dépôt de matériaux et fusion			Fusion sur lit de poudre	
Forme d'apport	Poudre	Fil	Fil	Poudre	
Source d'énergie	Laser	Faisceau d'electrons	Arc électrique	Laser	Faisceau d'electrons
Puissance (W)	100-3000	500-2000	1000-3000	50-1000	50-1000
Vitesse de dépôt (g/s)	0,1-1	0,1-2	0,2-2,8	-	-
Taille maximale de construction (mm x mm x mm)	2000x1500x750	2000x1500x750	5000x3000x1000	500x280x320	500x280x320
Précision dimentionnelle (mm)	0,5-1	1-1,5	Géométries trop complexes inatégnables	0,04-0,2	0,04-0,2
Rugosité (µm)	4-10	8-15	Necessite un usinage de finition	7-20	7-20
Post process	CIC et usinage de finition	Usinage de finition	Ré-usinage et usinage de finition	CIC parfois recommandé	CIC parfois recommandé







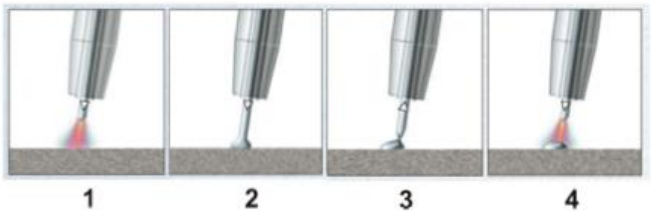


+ projection à froid (Coldspray)

Fabrication Additive Arc Fil : MIG-CMT

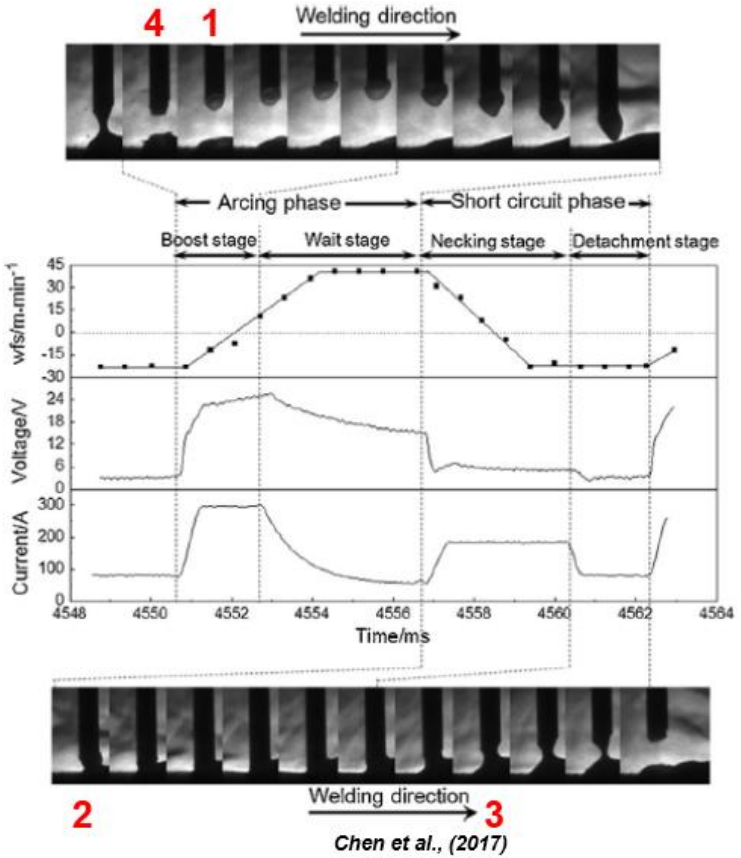
Metal **I**nert **G**as – **C**old **M**etal **T**ransfert

- Procédé contrôlé
- Mode de transfert peu énergétique
- Couplage d'une impulsion électrique + mécanique



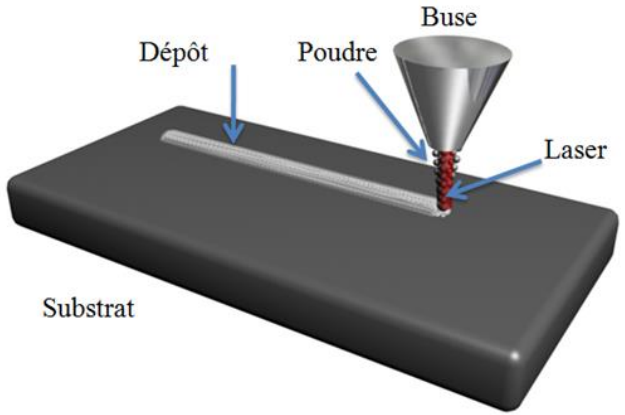
1 - Approche fil + l'arc s'établit + création d'une goutte
2 - Le fil apporte la goutte dans le bain de fusion + CC : poste I ≈ 0
3 - Le fil se rétracte et détache la goutte
4 - Le fil ressort et le cycle redémarre

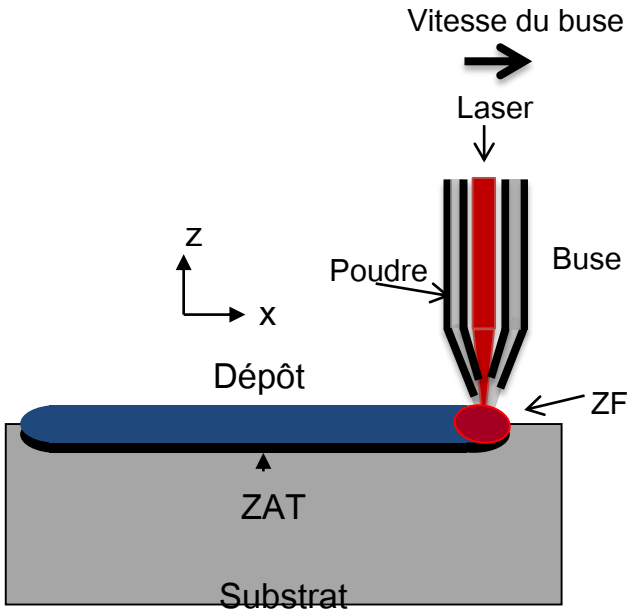
Fronius, (2011)

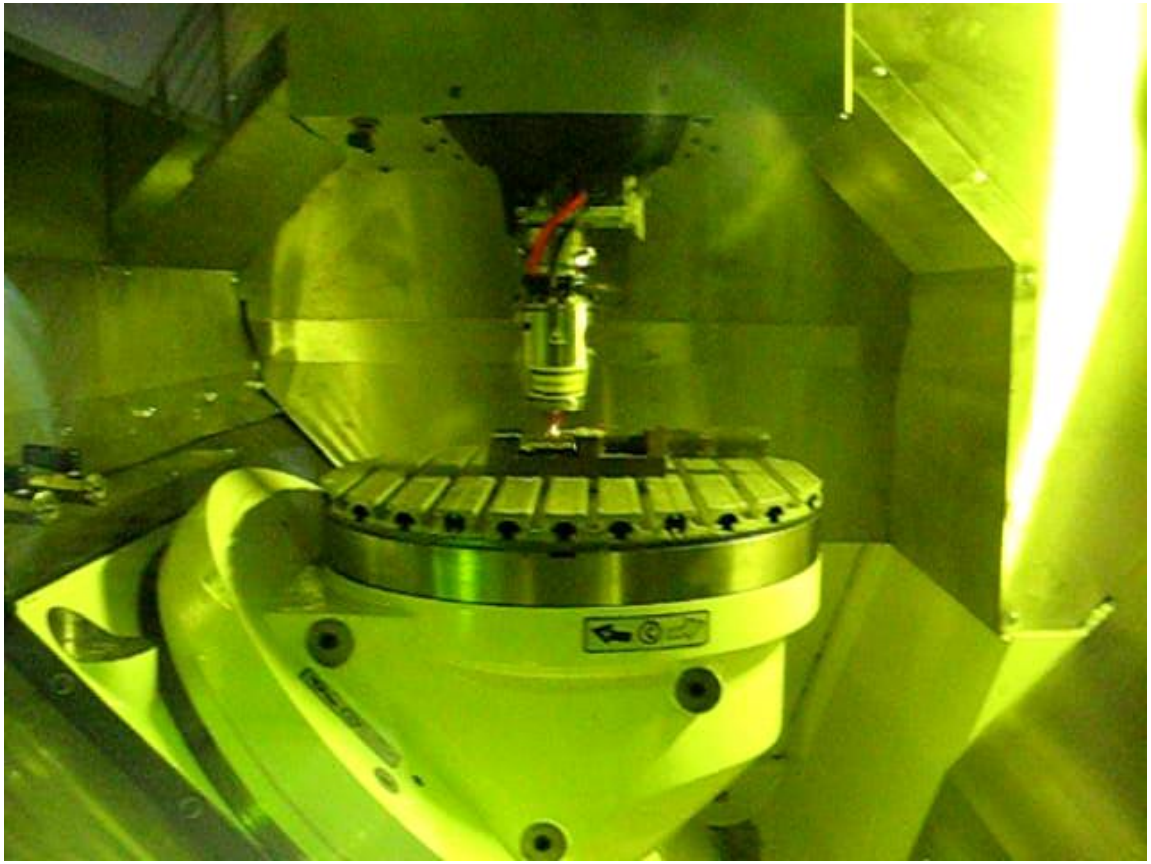


Chen et al., (2017)

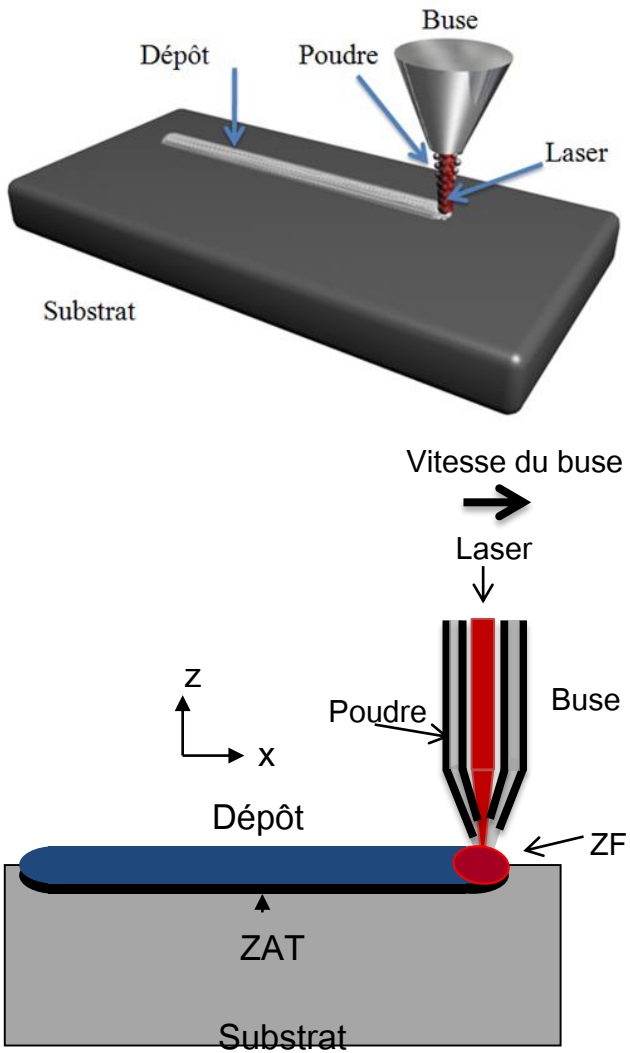
Direct Metal Laser Deposition : projection de la poudre dans le faisceau laser

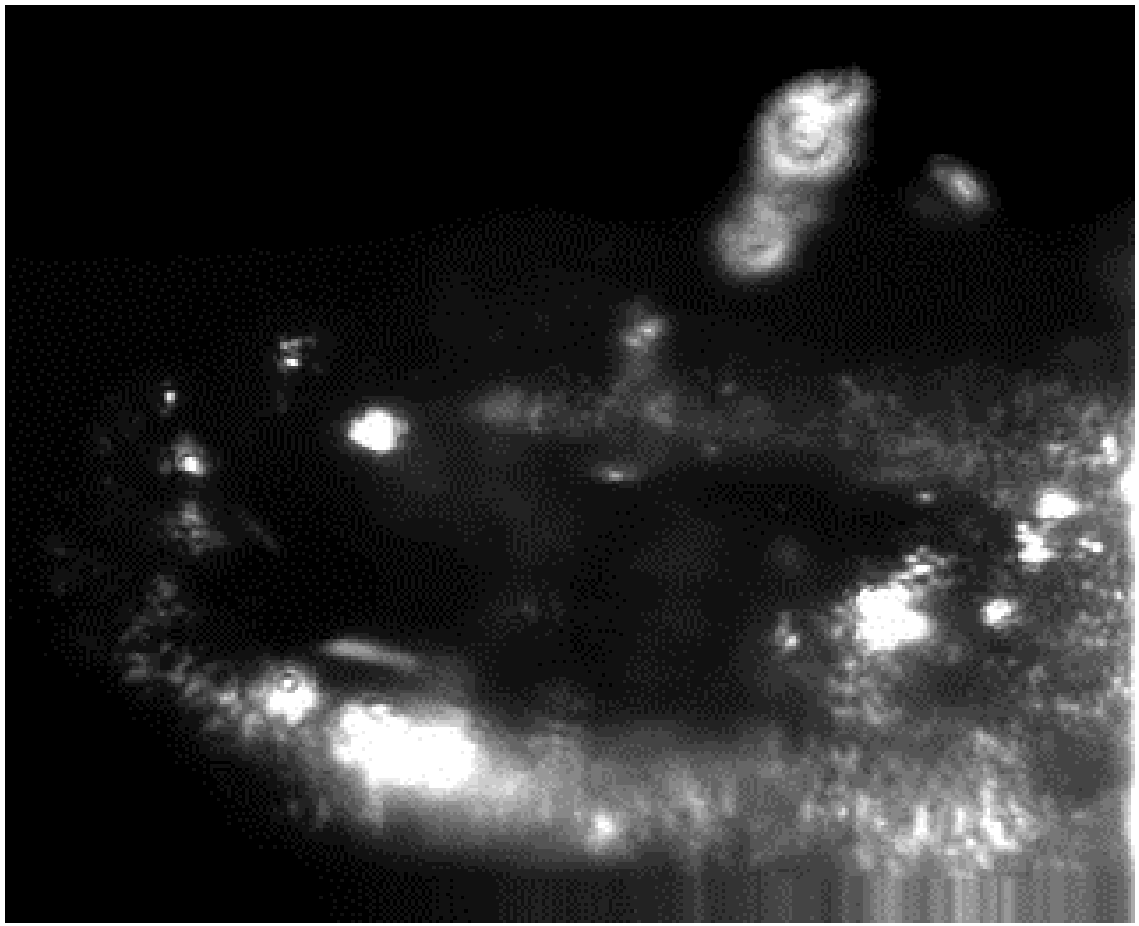






Direct Metal Laser Deposition : projection de la poudre dans le faisceau laser

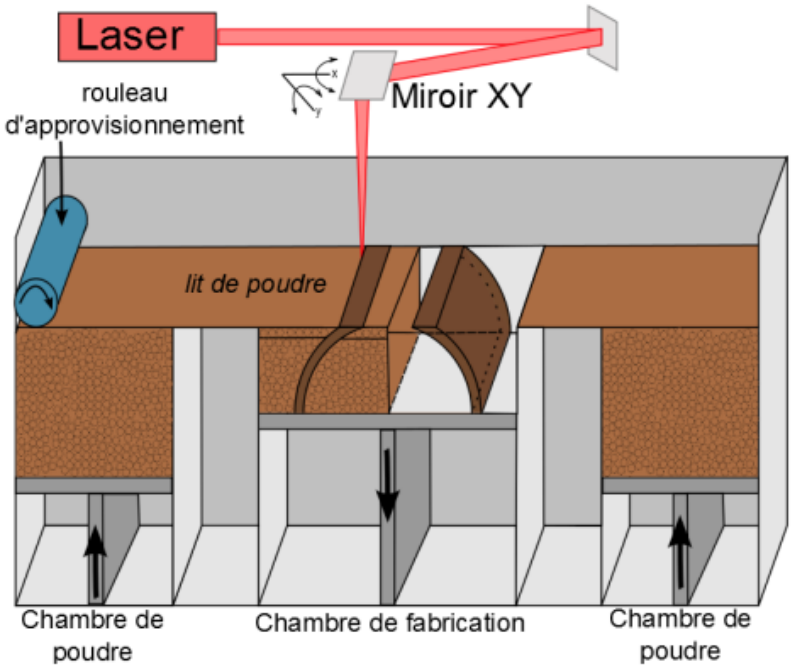




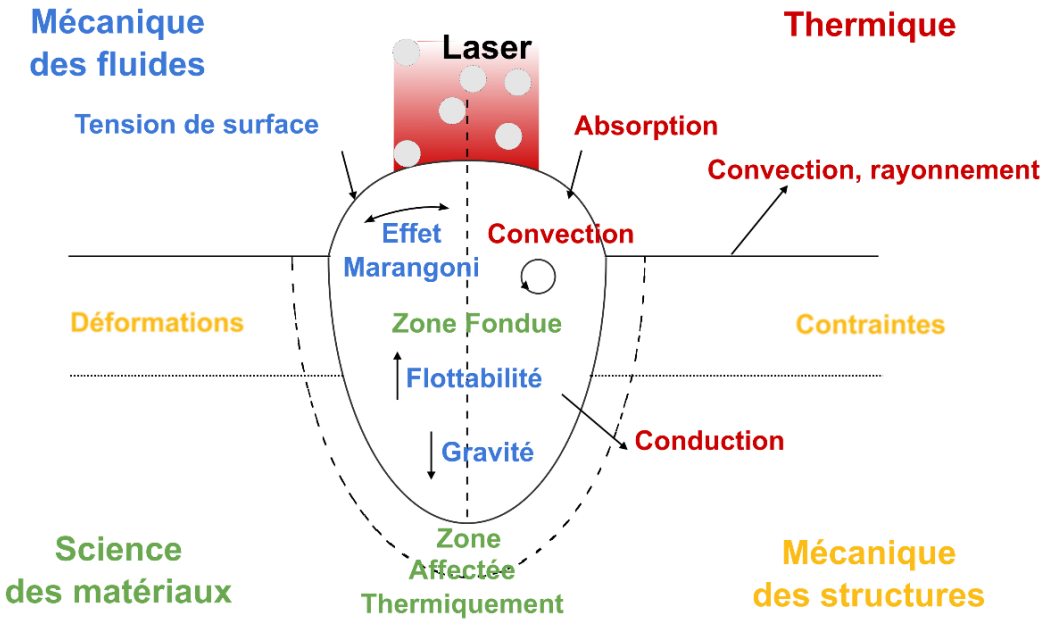
Observations of Particle-Melt Pool Impact Events DLMD

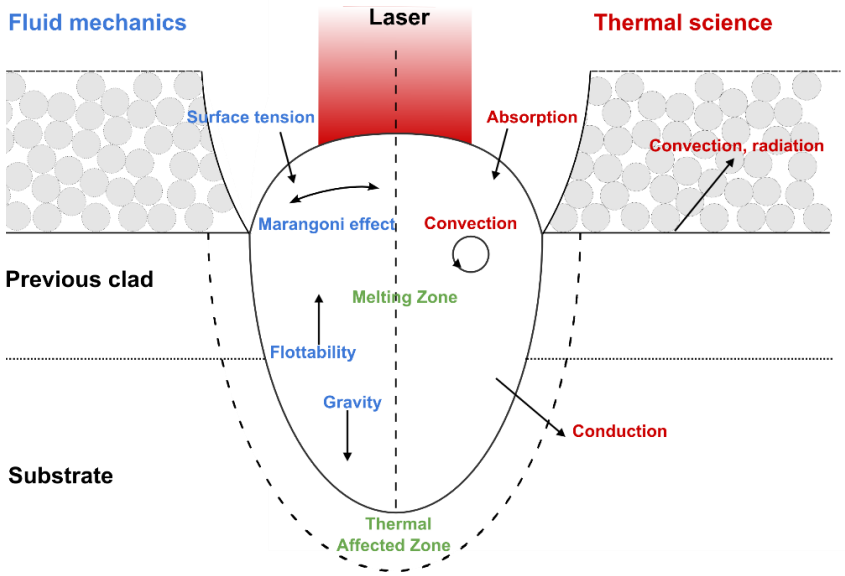
Additive Manufacturing 22 (2018) 368–374

Selective Laser Melting : Le faisceau laser provoque la fusion d'une couche de poudre pré-déposée



Fabrication additive & besoins en CND





Réaliser un cordon

Non fusion d'une partie de la poudre

Materials and Design 95 (2016) 431–445

Contents lists available at ScienceDirect

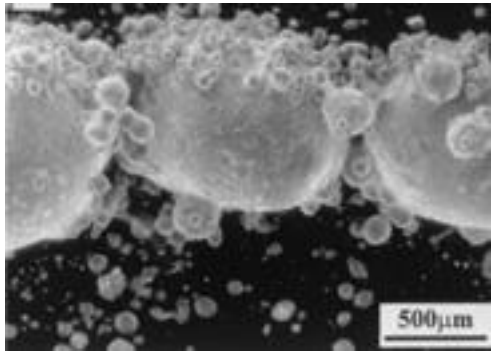
Materials and Design

journal homepage: www.elsevier.com/locate/matdes

Review of in-situ process monitoring and in-situ metrology for metal additive manufacturing

Sarah K. Everton [a,b,*], Matthias Hirsch [a], Petros Stravroulakis [a], Richard K. Leach [a], Adam T. Clare [a]

[a] Department of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, University Park, Nottingham NG72RD, United Kingdom
[b] Manufacturing Technology Centre, Ansty Park, Coventry CV7 9JU, United Kingdom



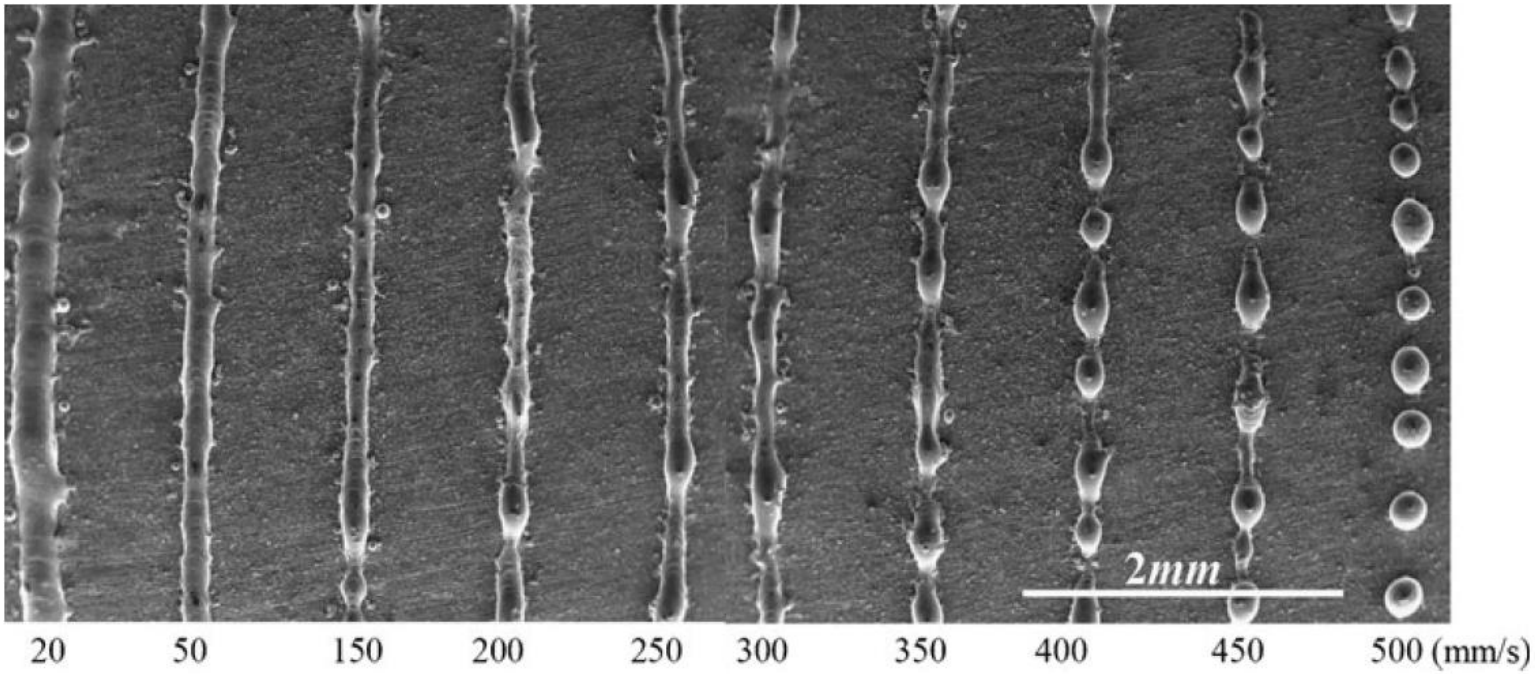
Effet « balling »

Int J Adv Manuf Technol (2012) 59:1025–1035
DOI 10.1007/s00170-011-3566-1

ORIGINAL ARTICLE

Balling behavior of stainless steel and nickel powder during selective laser melting process

Ruidi Li · Jinhui Liu · Yusheng Shi · Li Wang · Wei Jiang



Fabrication additive & besoins en CND

Acta Materialia 114 (2016) 33–42

Contents lists available at ScienceDirect

Acta Materialia

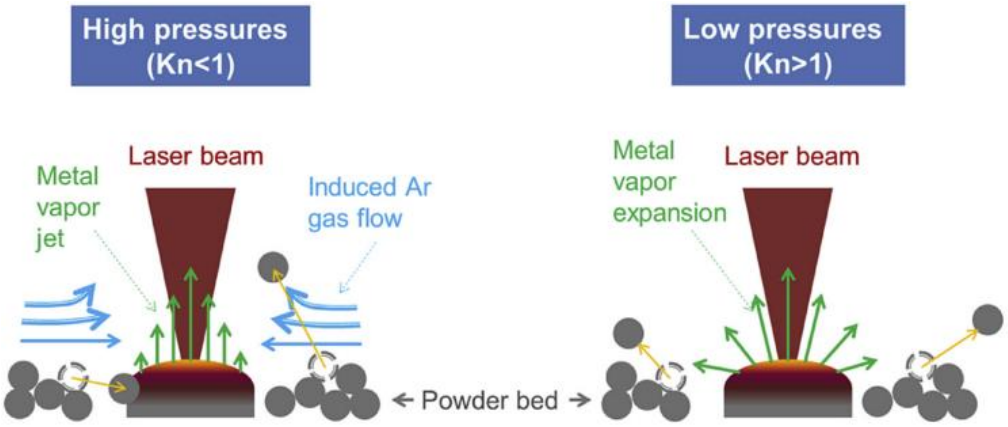
journal homepage: www.elsevier.com/locate/actamat

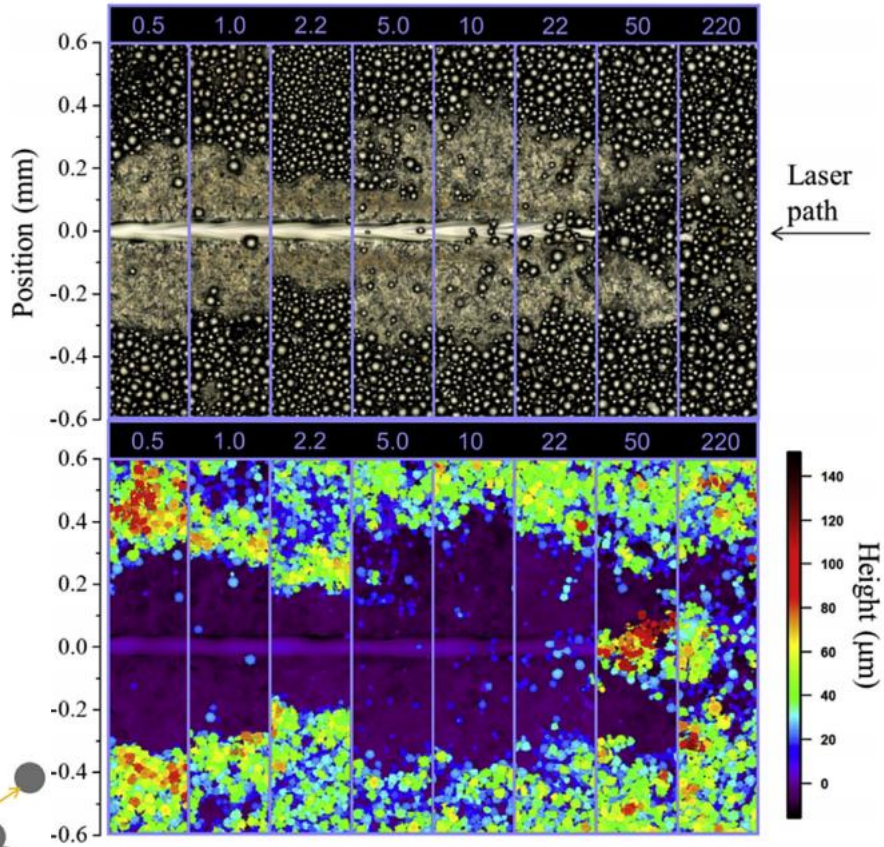
Full length article

Denudation of metal powder layers in laser powder bed fusion processes

Manyalibo J. Matthews*, Gabe Guss, Saad A. Khairallah, Alexander M. Rubenchik, Philip J. Depond, Wayne E. King

Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550, USA





Vidéo : Denudation

Contents lists available at ScienceDirect

Acta Materialia

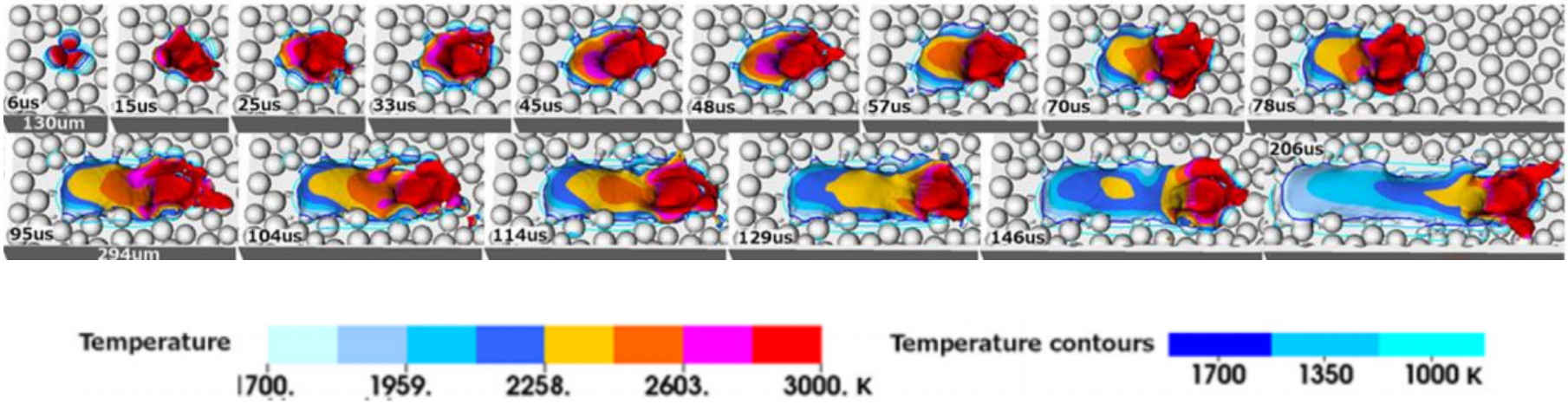
journal homepage: www.elsevier.com/locate/actamat

Full length article

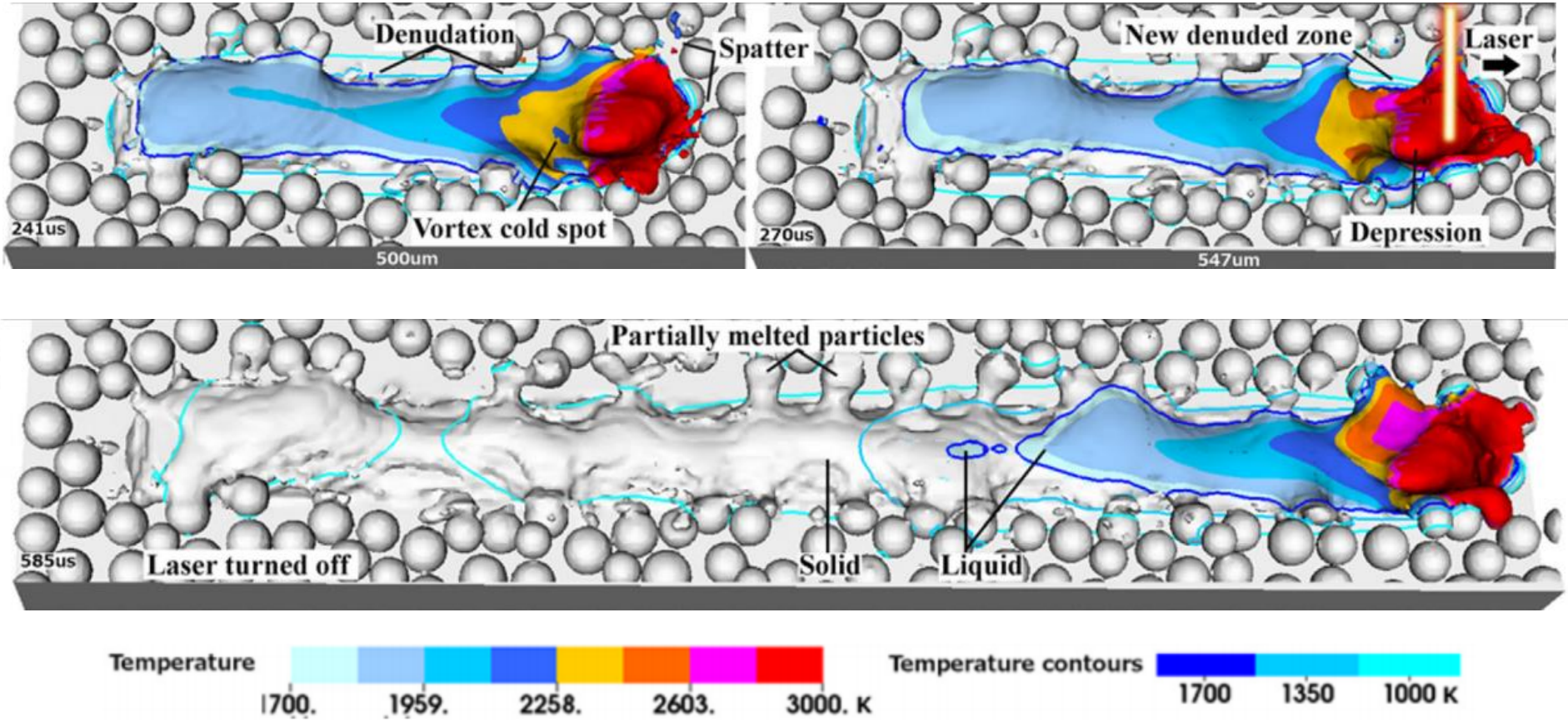
Laser powder-bed fusion additive manufacturing: Physics of complex melt flow and formation mechanisms of pores, spatter, and denudation zones

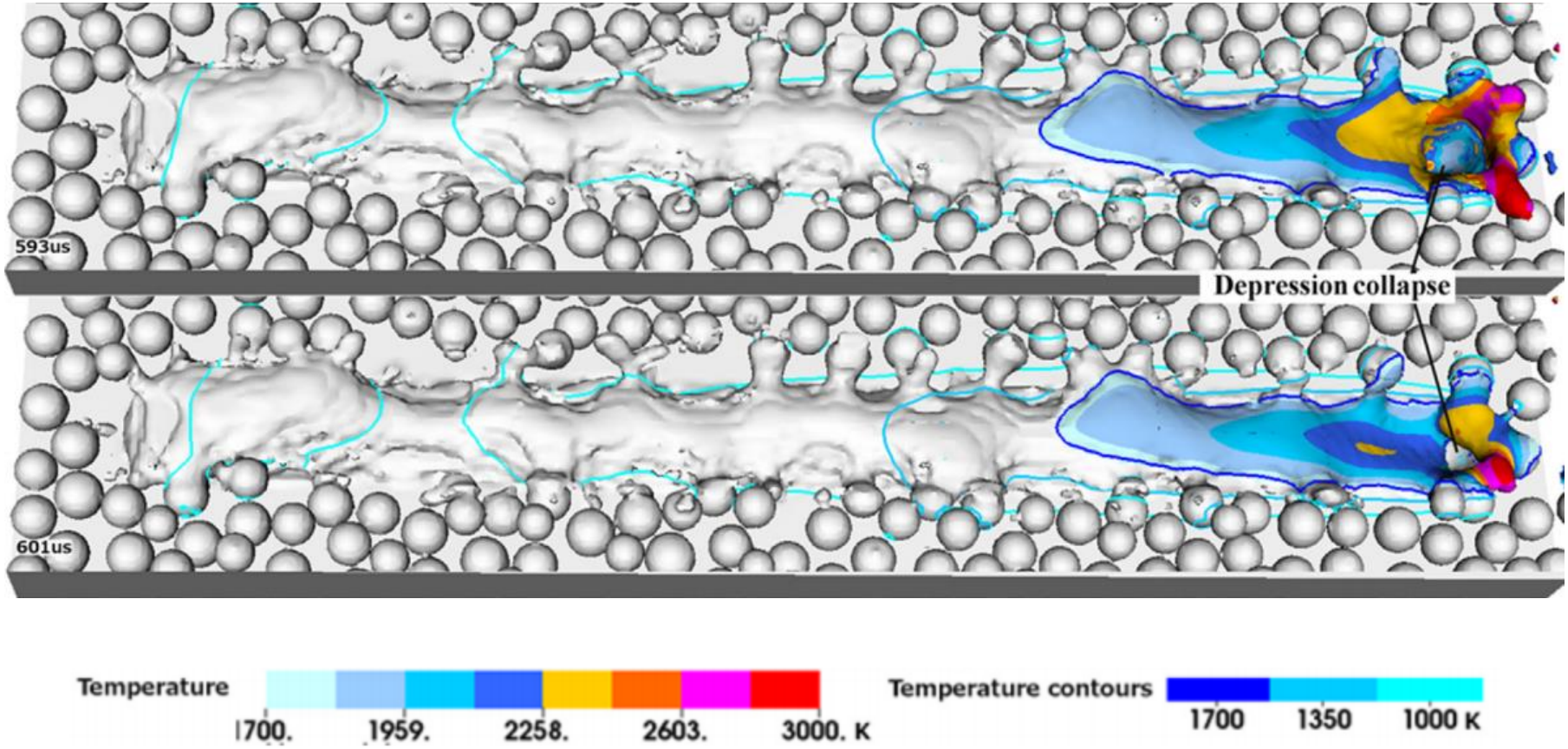
Saad A. Khairallah*, Andrew T. Anderson, Alexander Rubenchik, Wayne E. King

Lawrence Livermore National Laboratory, 7000 East Ave. Livermore, CA 94550, USA

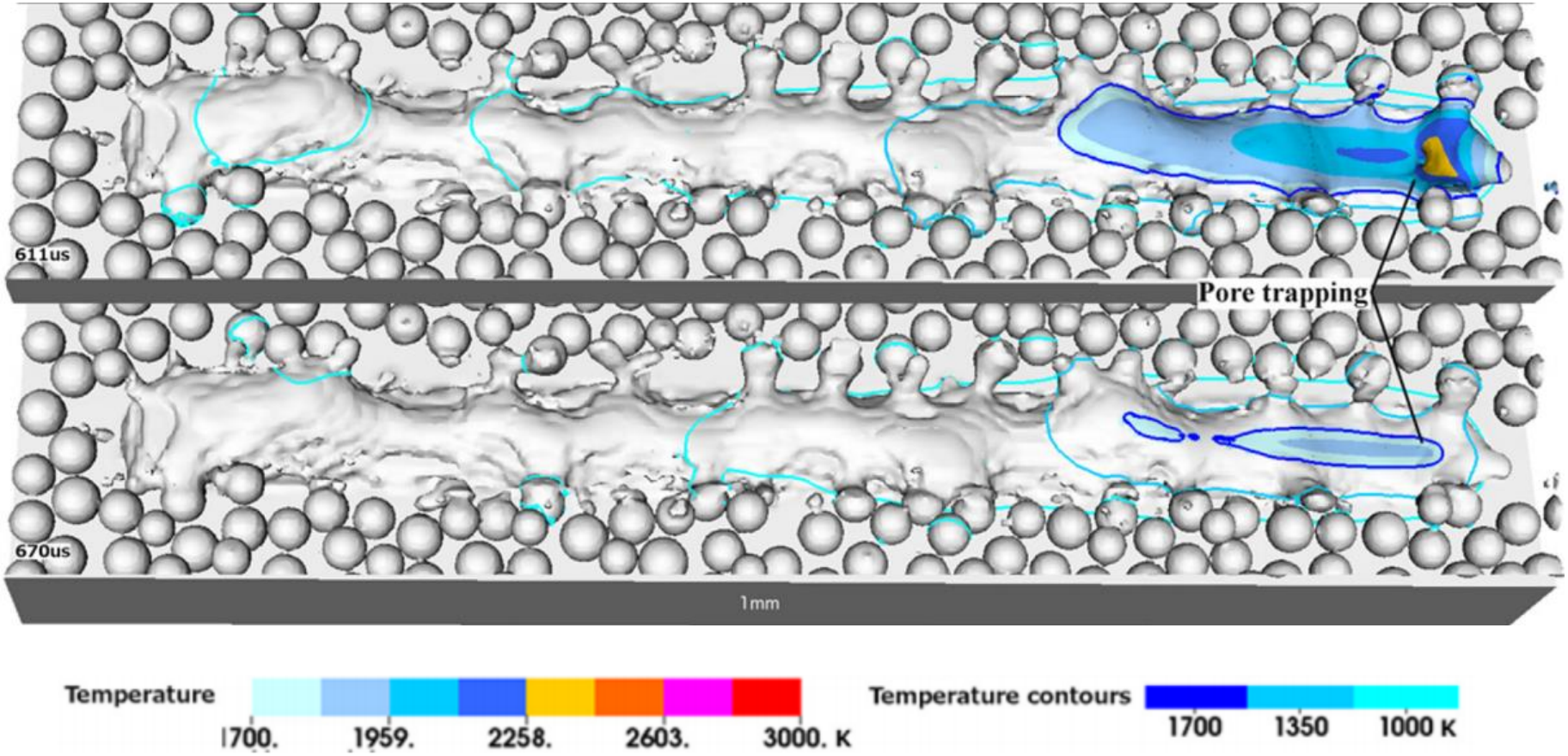


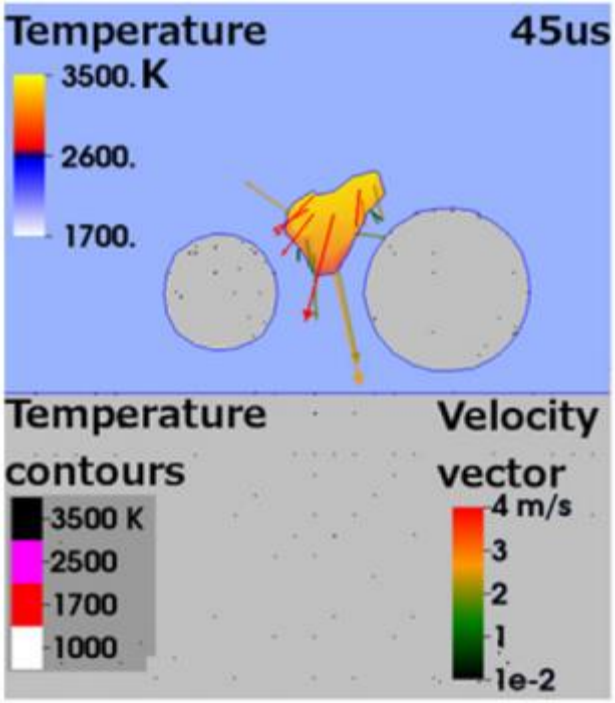
Fabrication additive & besoins en CND

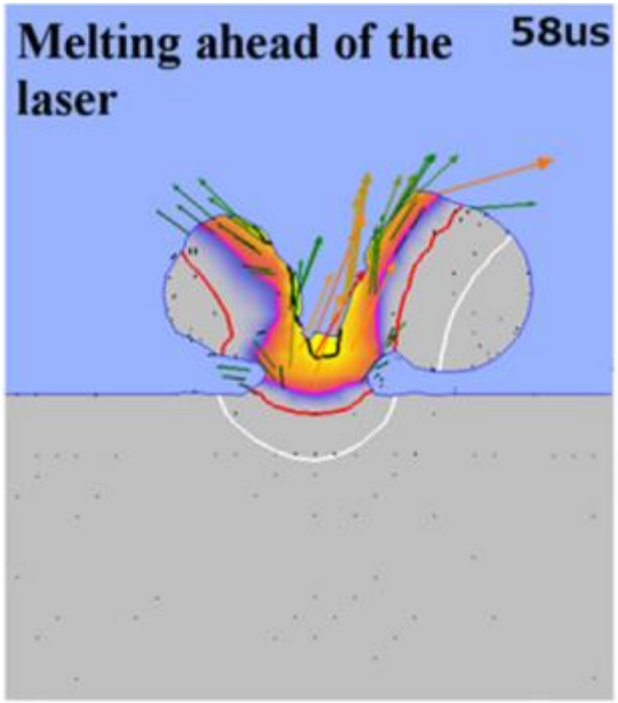


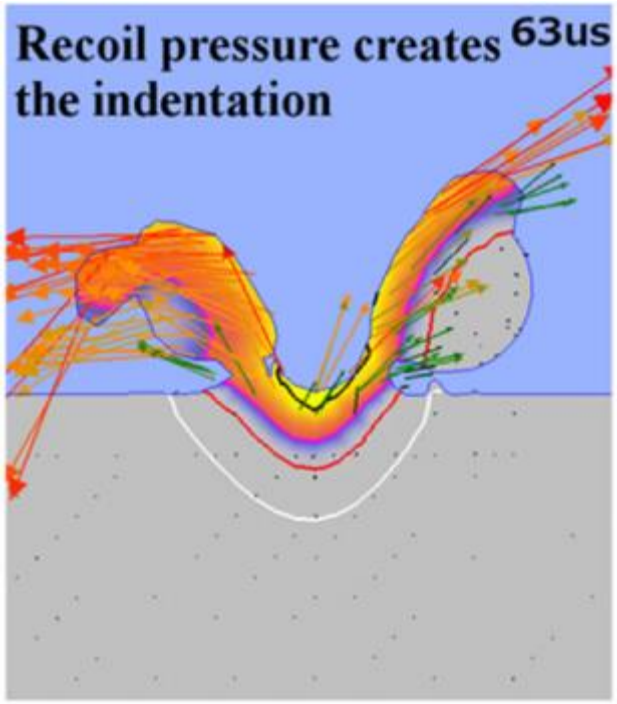

593us
Depression collapse
601us
Temperature
1700.
1959.
2258.
2603.
3000. K
Temperature contours
1700
1350
1000 K

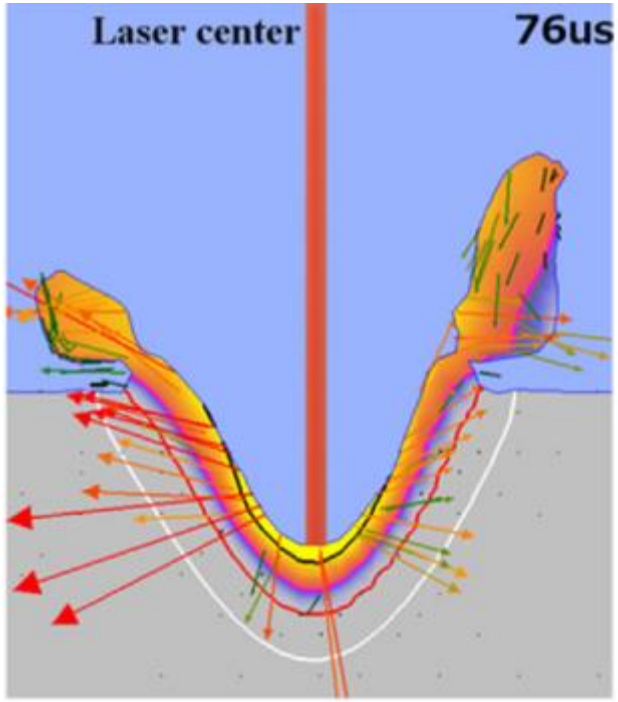
Fabrication additive & besoins en CND

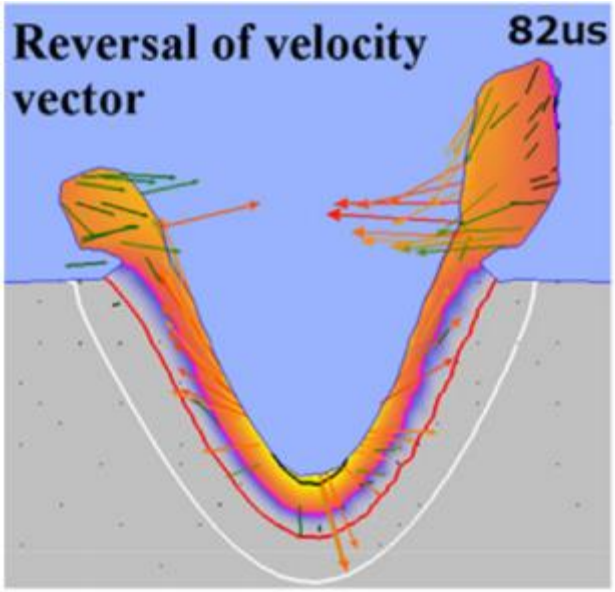


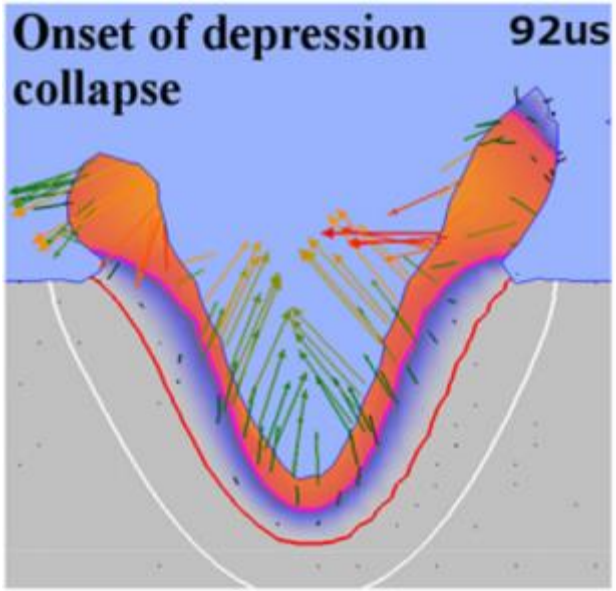

Temperature
45us
3500. K
2600.
1700.
Temperature
contours
3500 K
2500
1700
1000
Velocity
vector
4 m/s
3
2
1
1e-2

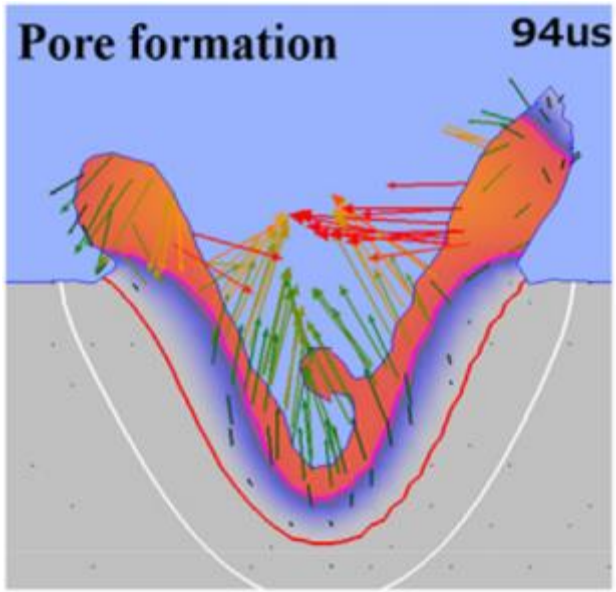

Melting ahead of the laser
58us

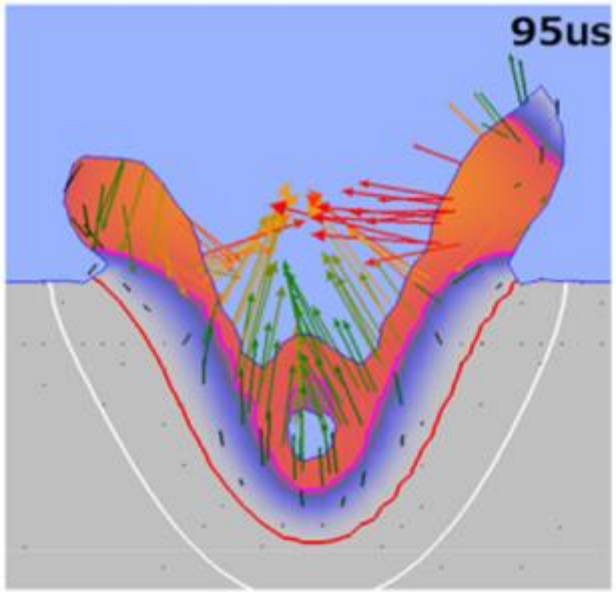

Recoil pressure creates the indentation
63us


Laser center
76us


Reversal of velocity vector
82us

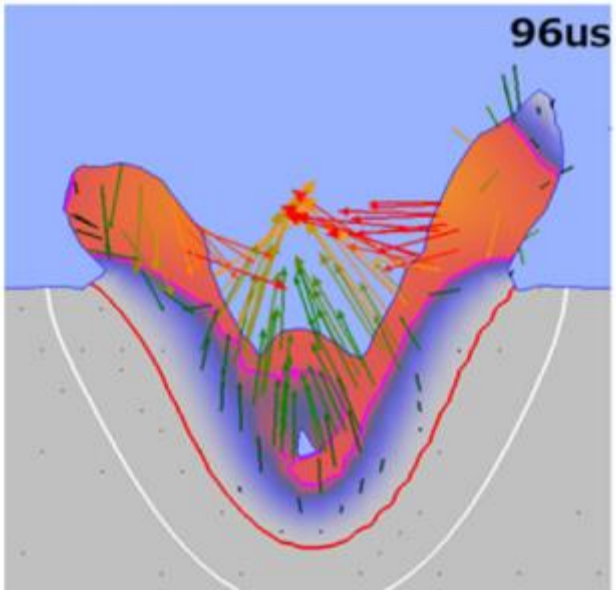

Onset of depression collapse
92us

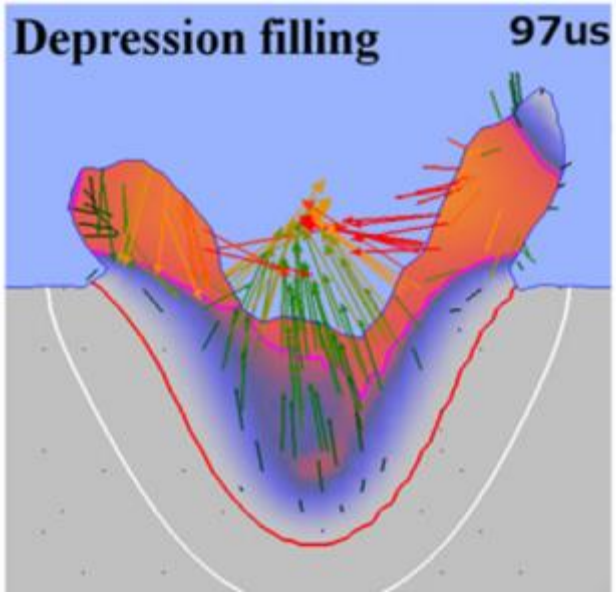

Pore formation
94us

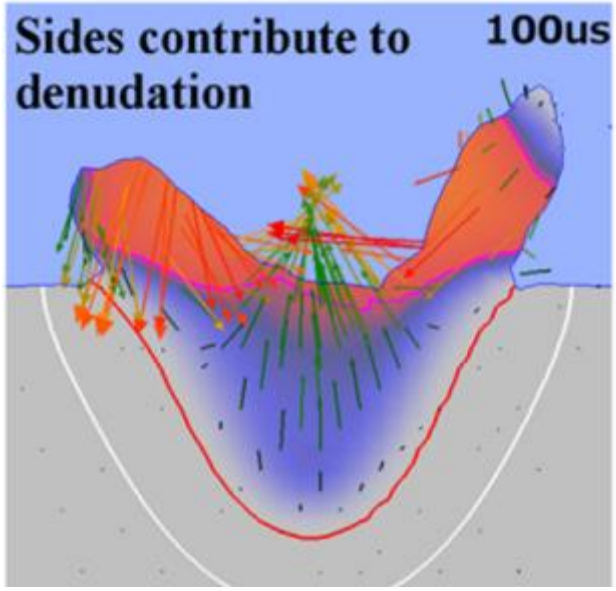


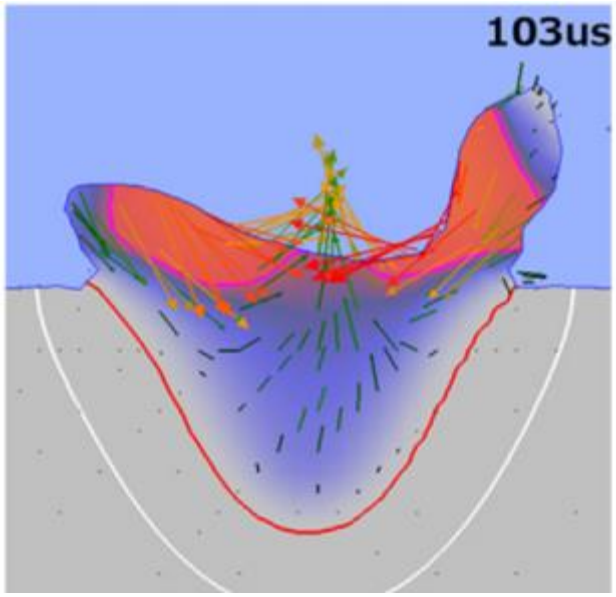
Formation de porosités :

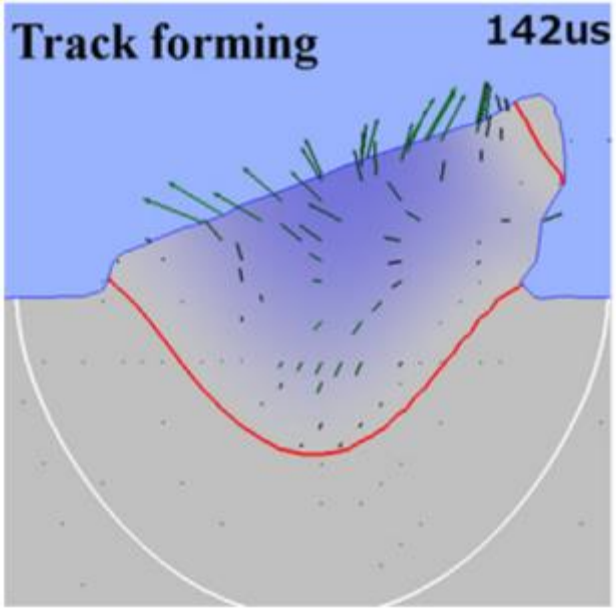
- Dynamique du bain et/ou génération de gaz (ex : Aluminium)
- Viscosité du bain (matériau)
- Dimensions du bain, vitesse du laser

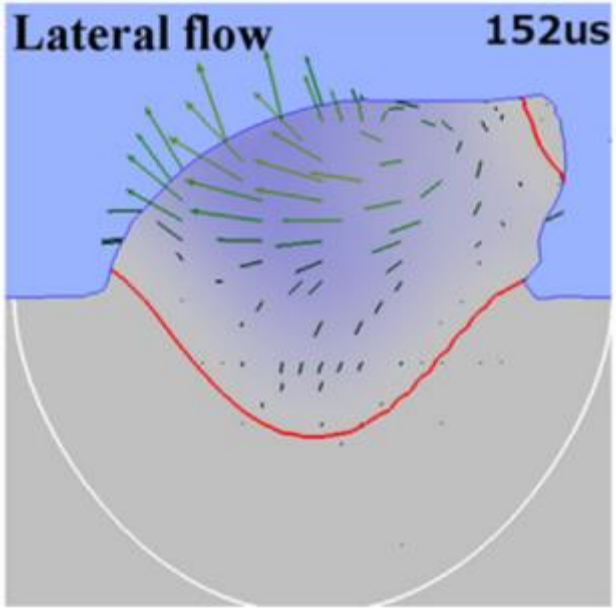

96us

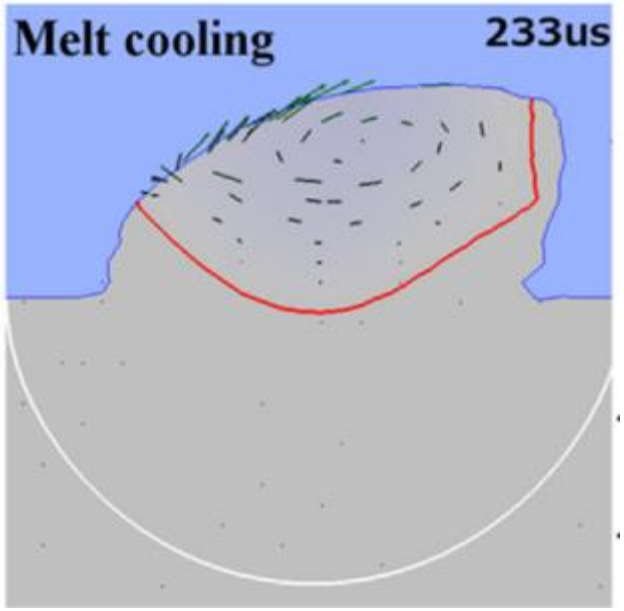

Depression filling
97us

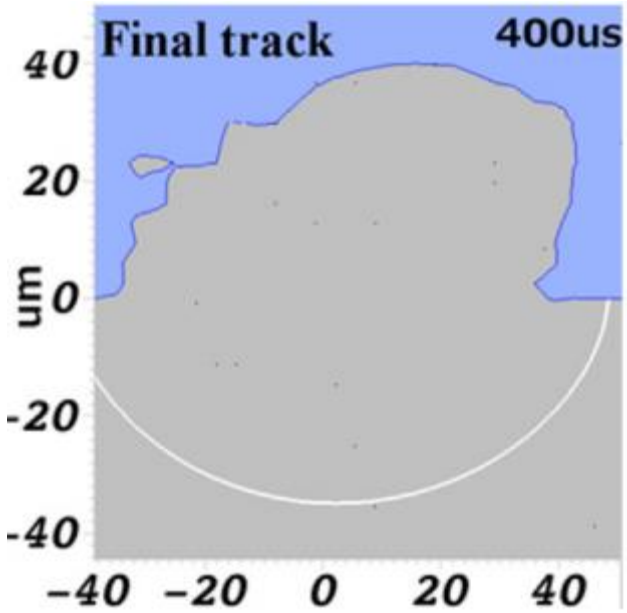

Sides contribute to denudation
100us


103us


Track forming
142us


Lateral flow
152us


Melt cooling
233us


Final track
400us
40
20
0
-20
-40
um
-40
-20
0
20
40

Maîtriser la dynamique du bain

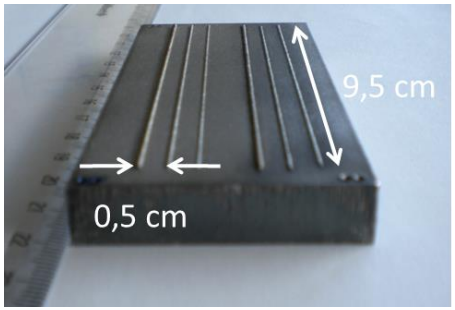
Réaliser un mur

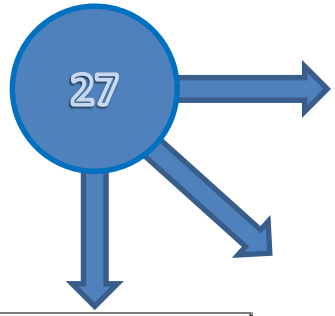
3 paramètres avec 3 niveaux

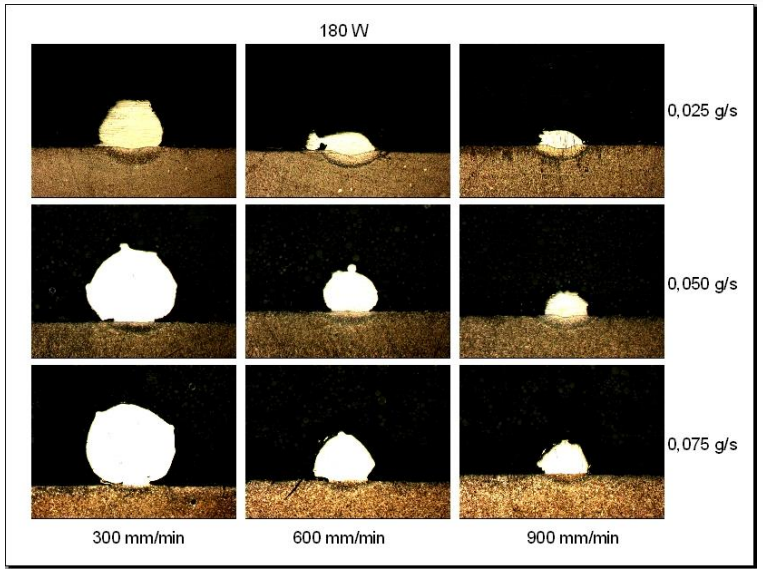
Puissance laser : P

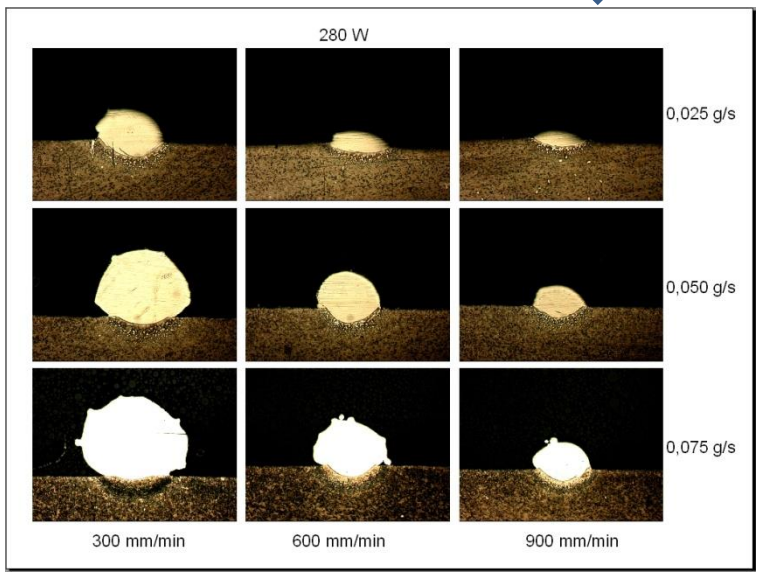
Débit de poudre : Q_m

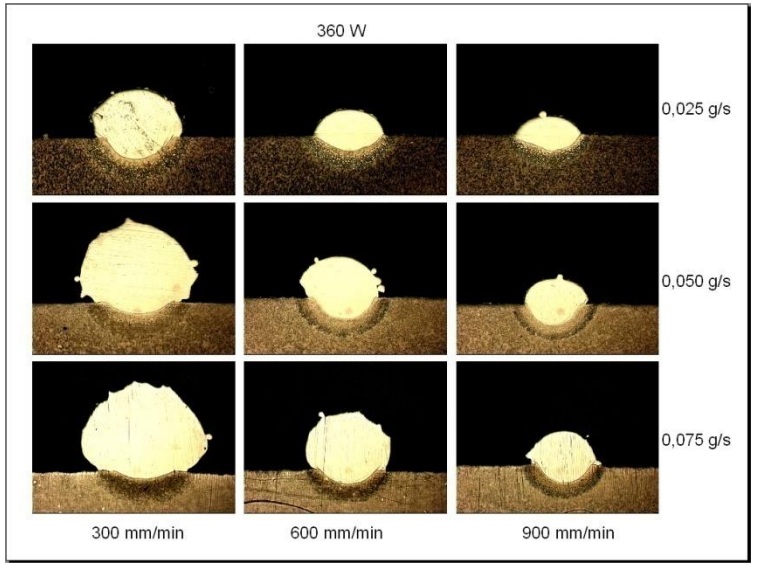
Vitesse relative : V



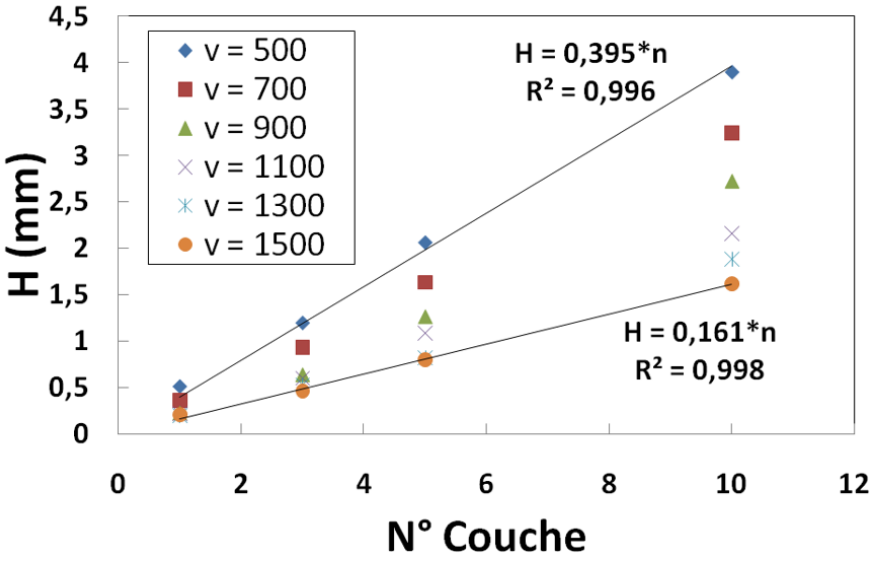


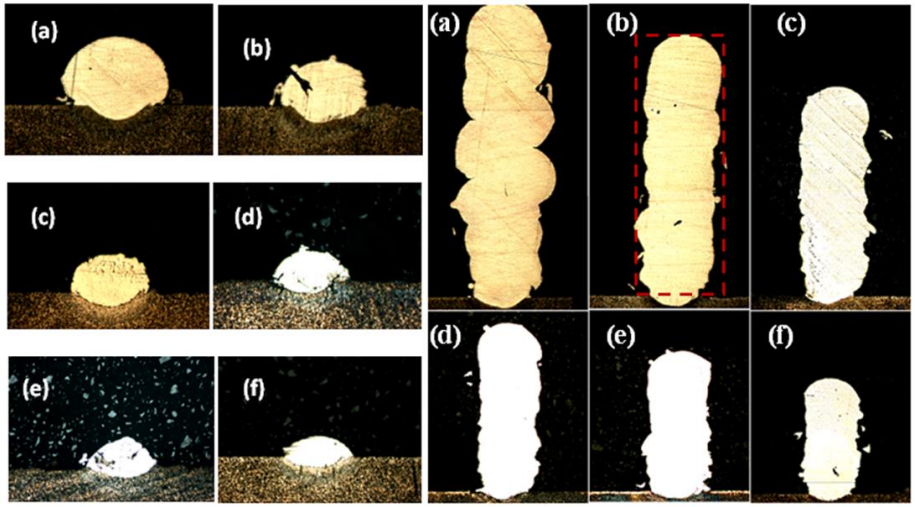






El Cheikh, H., Courant, B., Branchu, S., Hascoët, J.Y., Guillén, R., (2012). Direct laser fabrication process with coaxial powder projection of 316L steel. Geometrical characteristics and microstructure characterization of wall structures. Optics and Lasers in Engineering, 50(12), 1779-1784.





Relation linéaire entre la hauteur du mur et le nombre de couches

El Cheikh, H., Courant, B., Branchu, S., Hascoët, J.Y., Guillén, R., (2012). Direct laser fabrication process with coaxial powder projection of 316L steel. Geometrical characteristics and microstructure characterization of wall structures. Optics and Lasers in Engineering, 50(12), 1779-1784.

Contents lists available at ScienceDirect

Additive Manufacturing

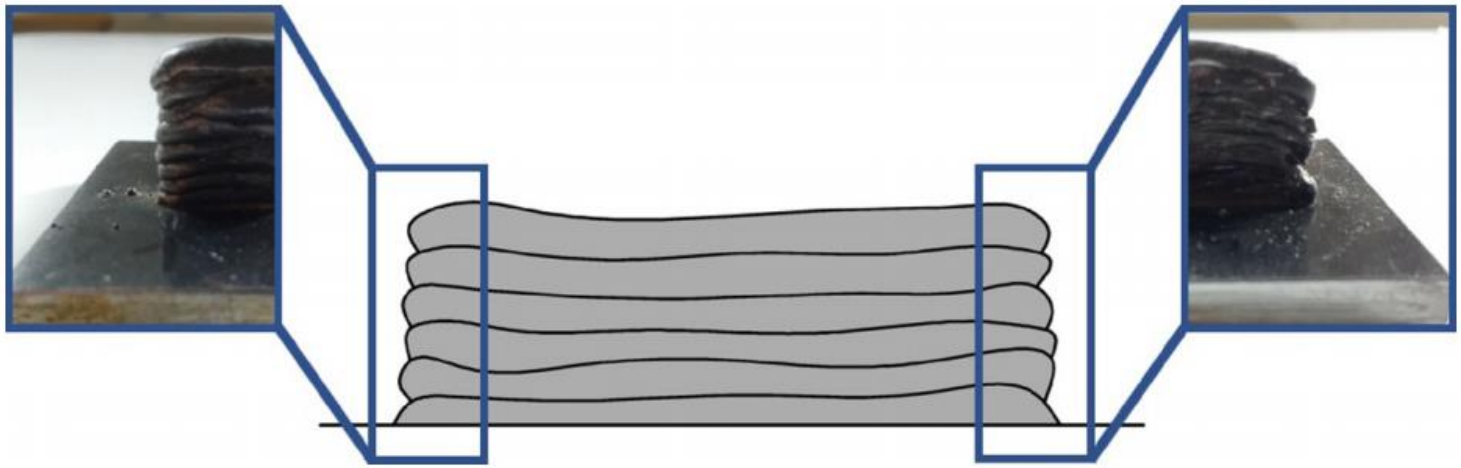
journal homepage: www.elsevier.com/locate/addma

Full Length Article

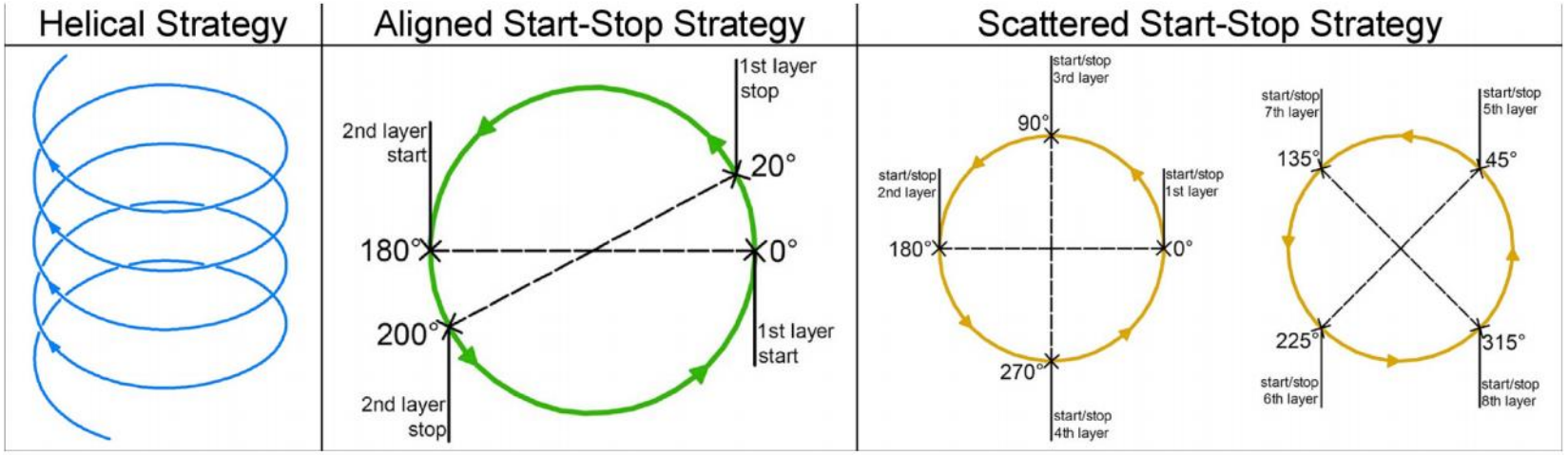
Feature based three axes computer aided manufacturing software for wire arc additive manufacturing dedicated to thin walled components

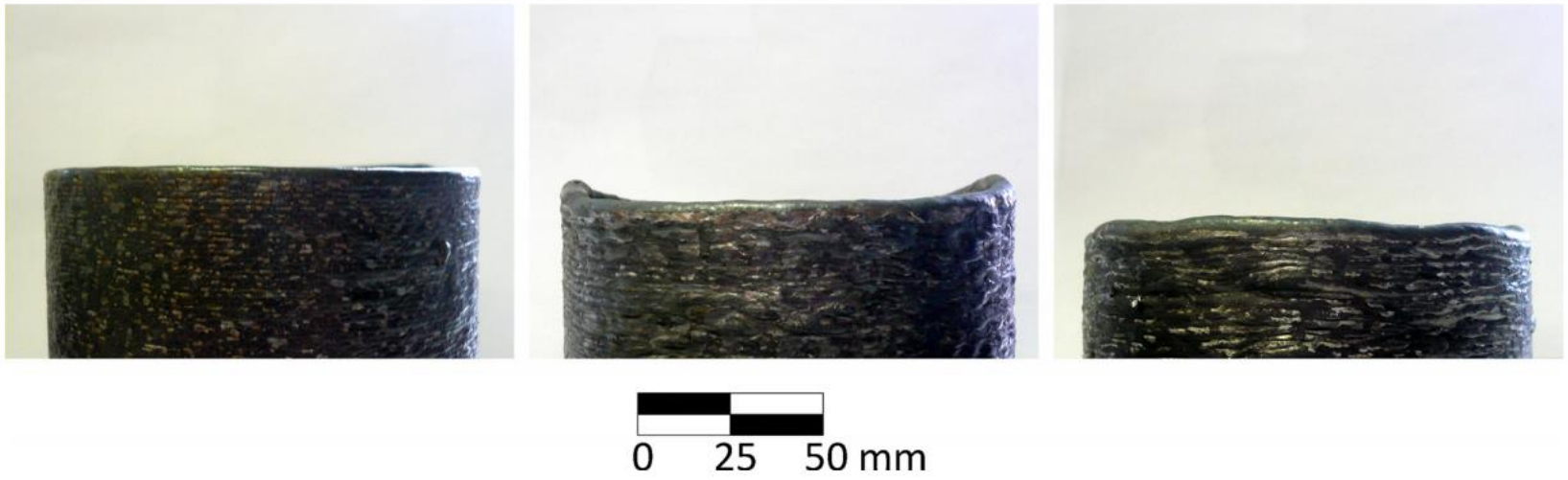
Giuseppe Venturini*, Filippo Montevecchi, Francesco Bandini, Antonio Scippa, Gianni Campatelli

Department of Industrial Engineering, University of Firenze, Via di Santa Marta 3, Firenze, 50139, Italy



Fabrication additive & besoins en CND





Maîtriser la distance buse – pièce et la géométrie du bain

Réaliser une structure pleine

Additive Manufacturing 14 (2017) 39–48

Contents lists available at ScienceDirect

Additive Manufacturing

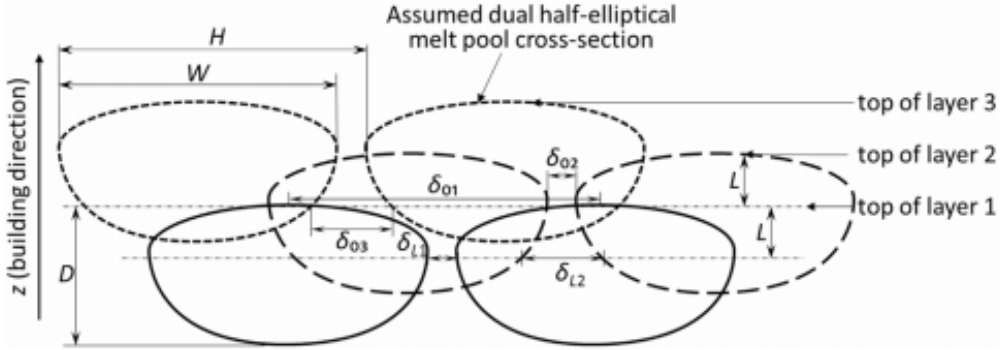
journal homepage: www.elsevier.com/locate/addma

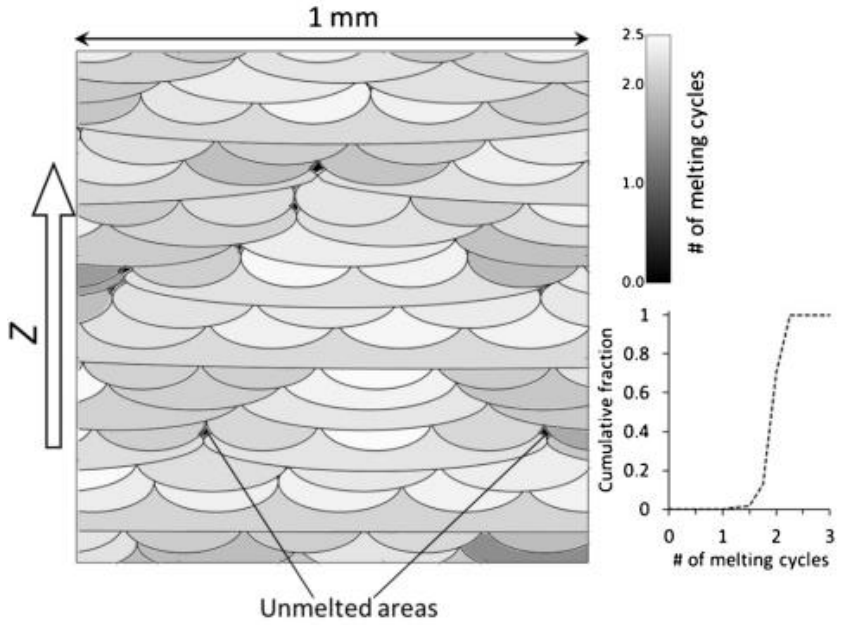
Full Length Article

Prediction of lack-of-fusion porosity for powder bed fusion☆

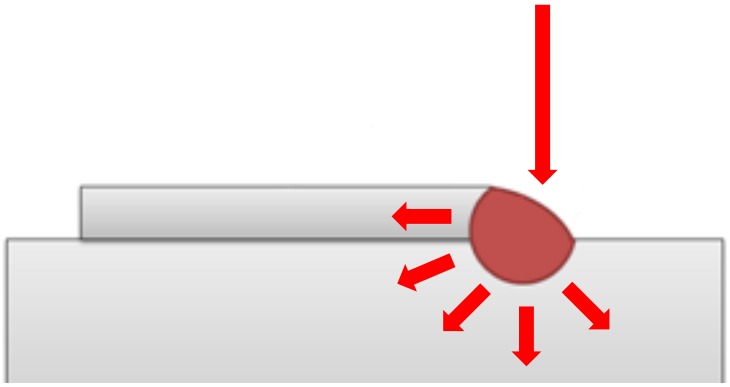
Ming Tang[a], P. Chris Pistorius[a,*], Jack L. Beuth[b]

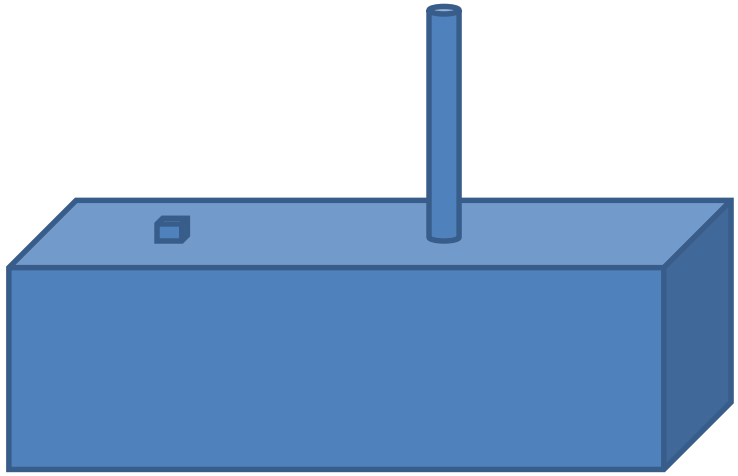
[a] Department of Materials Science and Engineering, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA, 15213, USA
[b] Department of Mechanical Engineering, Carnegie Mellon University, 5000 Forbes Avenue, Pittsburgh, PA, 15213, USA





Réaliser une pièce





Les conditions thermiques changent les paramètres doivent s'adapter

Simulations EF trop lourdes

Simulations analytiques trop grossières

→ Suivi in-situ par CND

Fabrication additive & besoins en CND

Additive Manufacturing 12 (2016) 1–15

Contents lists available at ScienceDirect

Additive Manufacturing

journal homepage: www.elsevier.com/locate/addma

Understanding the effect of laser scan strategy on residual stress in selective laser melting through thermo-mechanical simulation

L. Parry, I.A. Ashcroft*, R.D. Wildman

University of Nottingham, Nottingham, NG7 2RD, UK

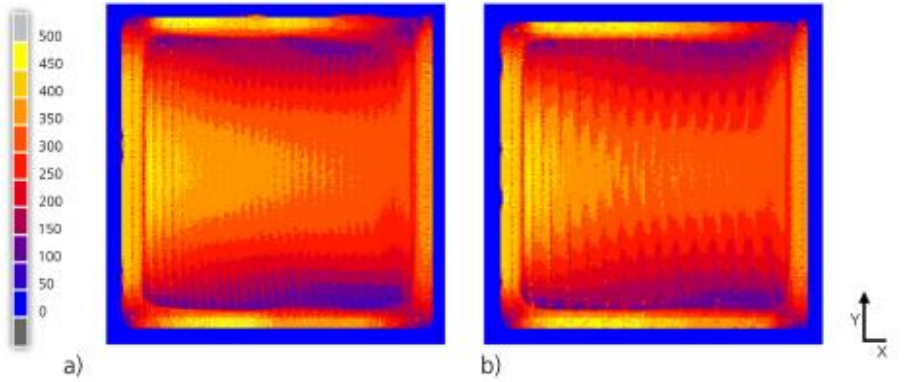
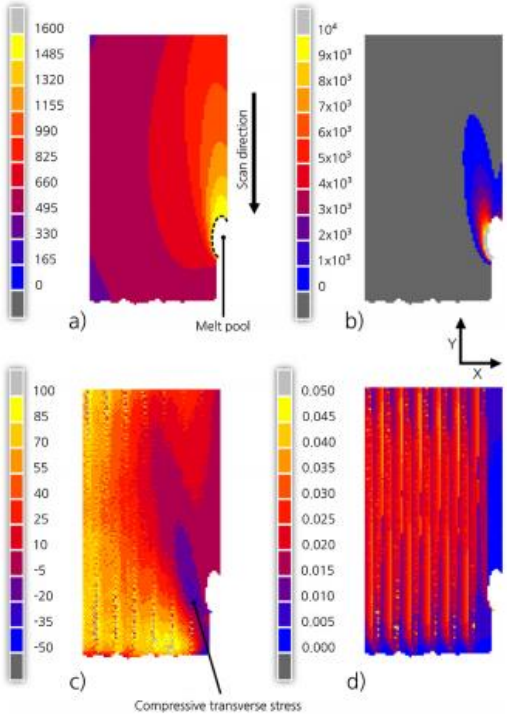
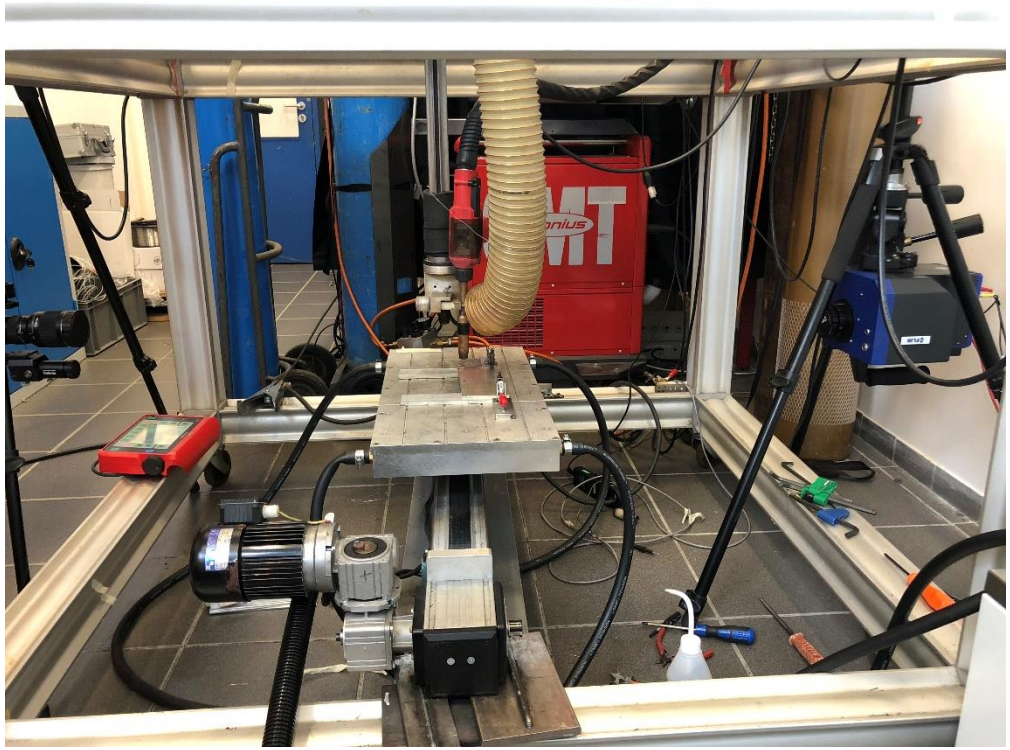


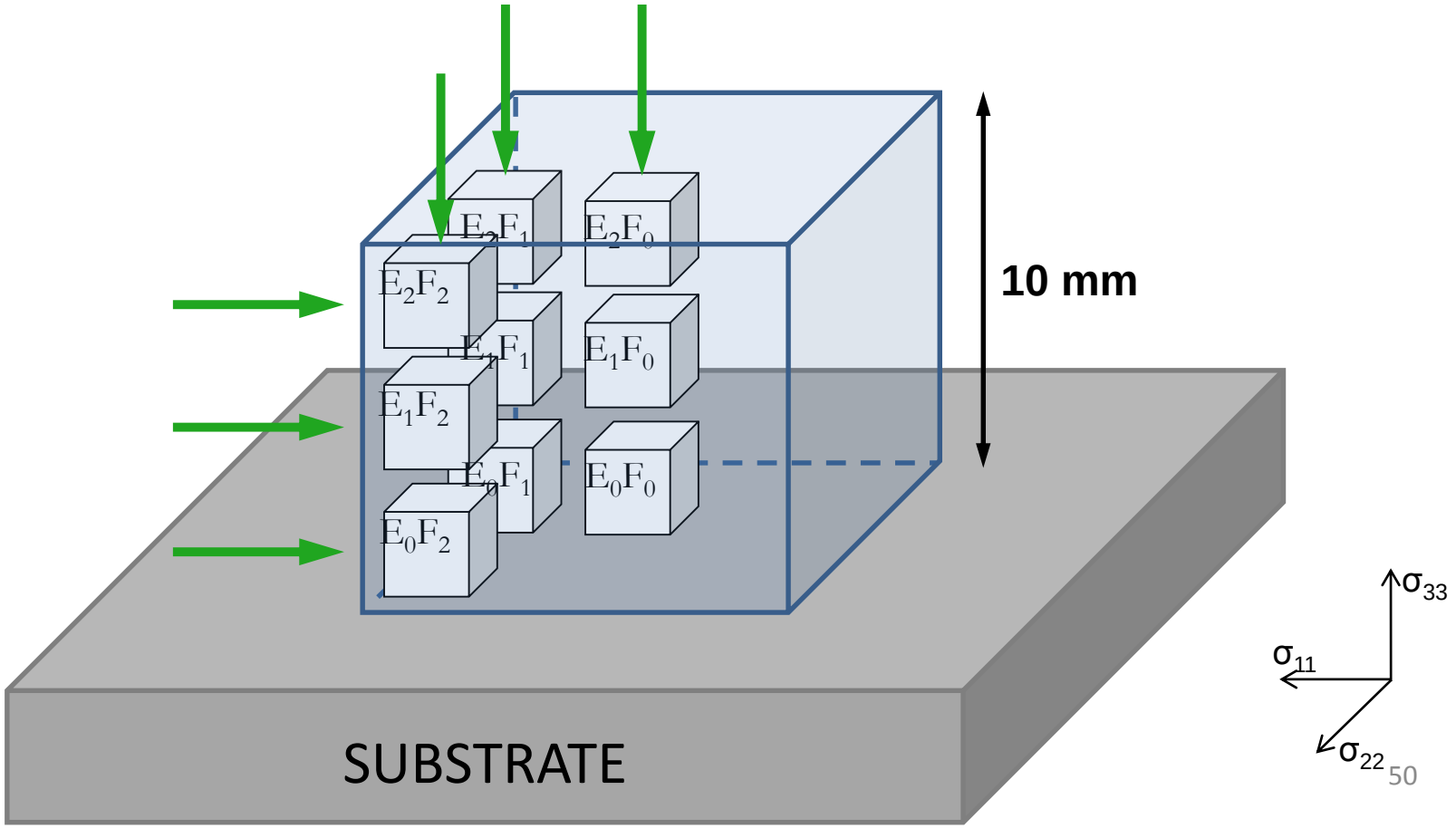
Fig. 15. Profiles views of von Mises stress distribution for 3 mm × 3 mm test case when using a) unidirectional, and b) alternating scan strategies



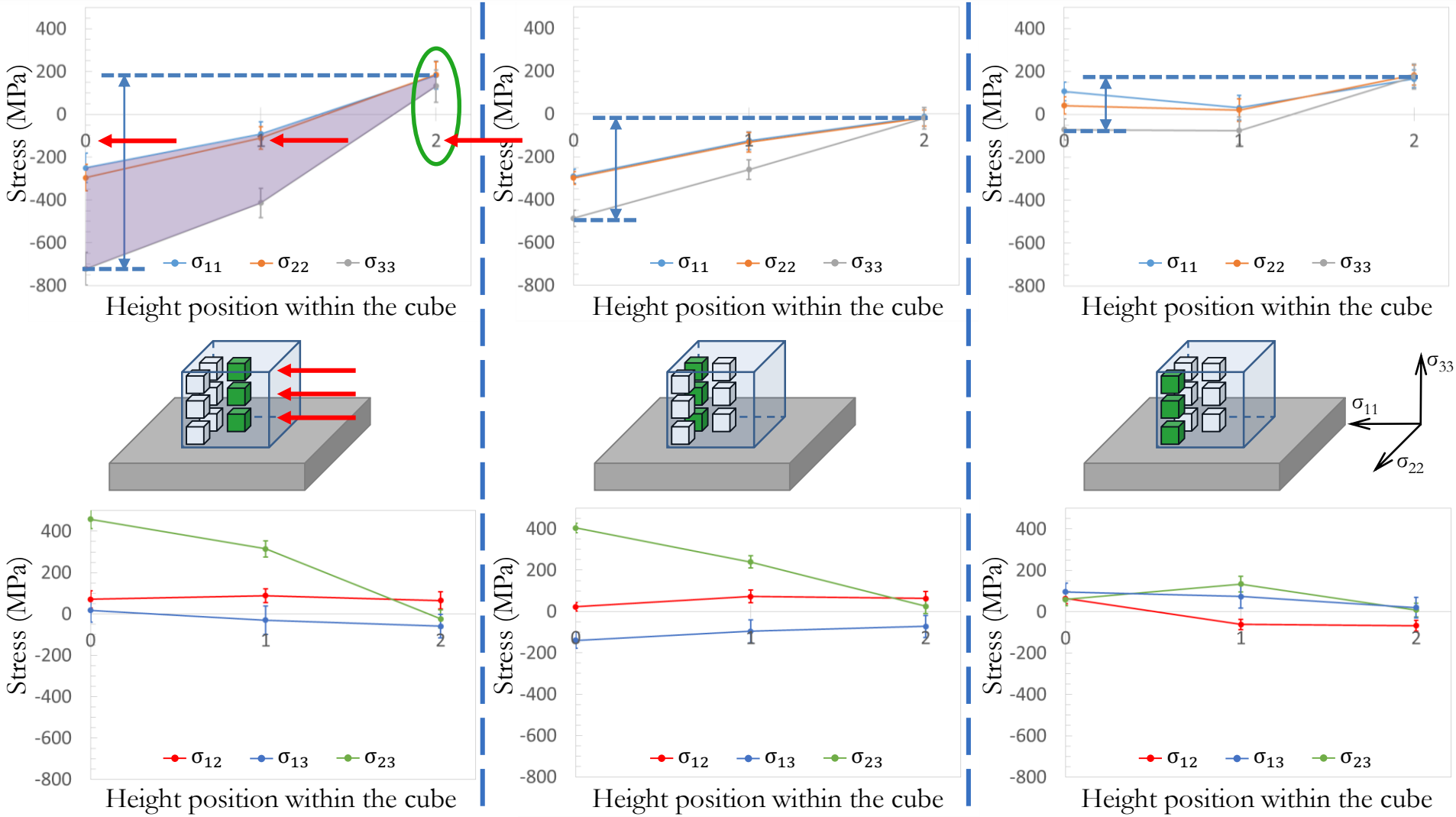


à gauche la camera haute vitesse et a droite la camera infra rouge

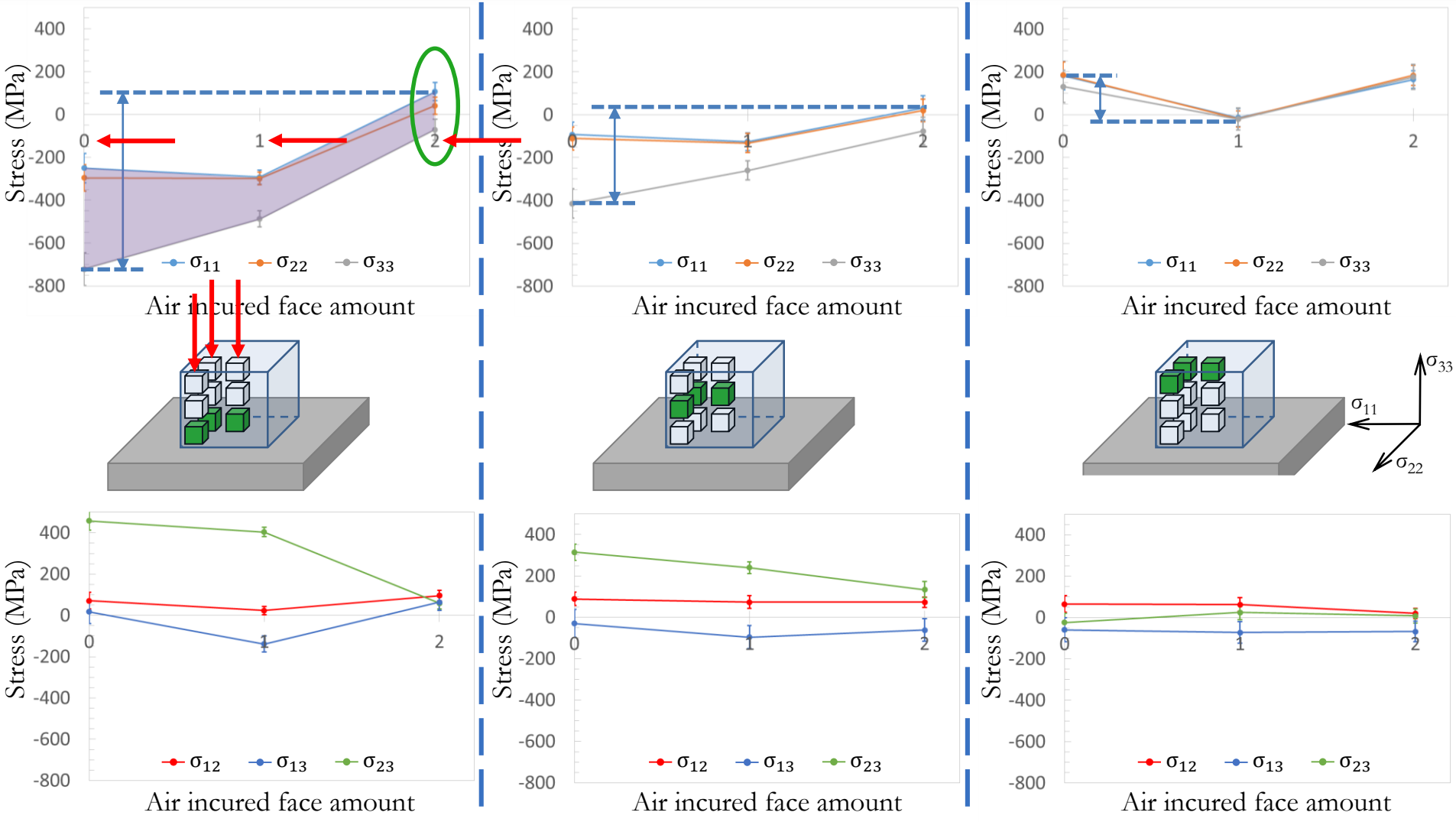
- Analysis of **9** volumes (strain gage) of **2×2×2 mm³** (200 µm from edges) distributed over the cube:
  - **Full stress tensor** analysis at **each gage position**:
    - ► Along each **column**: emphasis made on **thermal background (E_0 or E_1 or E_2)**
    - ► On each **level**: focus on **heat treatment** induced by the amount of **close surface (F_0 or F_1 or F_2)**



Fabrication additive & besoins en CND



- **Reduction** of **residual stress gradient magnitude** with **building height**
- **Homogeneous** and **lowered values close to upper surface**
- The **larger** quenching surface, the **smaller** residual stress **gradient magnitude**



- **Reduction** of **residual stress gradient magnitude** with **quenching face amount**
- **Homogeneous** and **lowered values close to corners**
- The **higher**, the **smaller** residual stress **gradient magnitude**

Maîtriser les phénomènes thermiques

Les CND doivent pouvoir contribuer à éviter les principaux problèmes rencontrés en fabrication additive :

Vérifier la bonne formation du cordon

Eviter la formation de porosités

Maîtriser la dynamique du bain

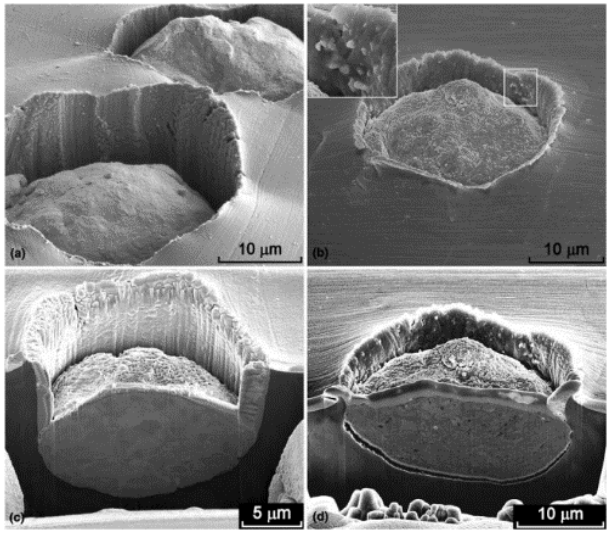
Assurer la stabilité lors de la fabrication de pièces hautes

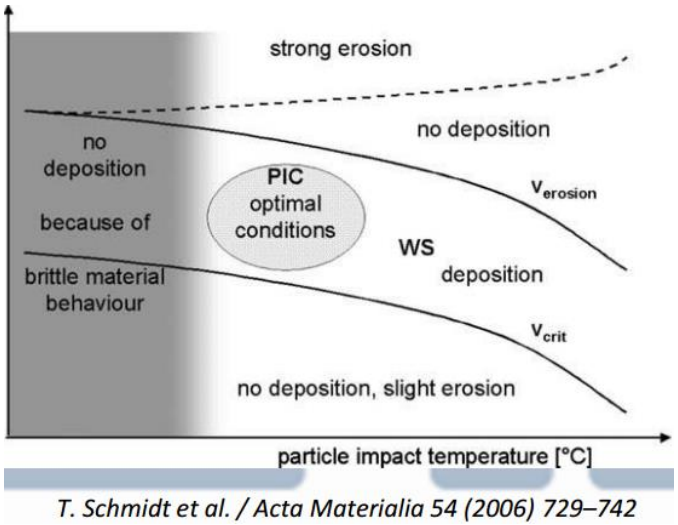
Maîtriser la distance buse – pièce et la géométrie du bain

Limiter la présence des contraintes résiduelles

Maîtriser les phénomènes thermiques

Un procédé de fabrication additive sans fusion : Projection à froid (cold spray)





T. Schmidt et al. / Acta Materialia 54 (2006) 729–742